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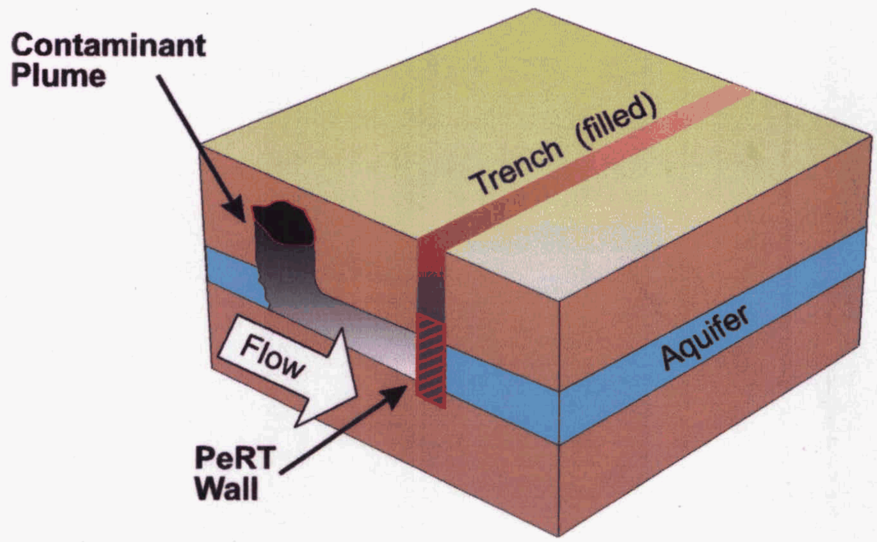
GJO-2000-148-TAR

Monticello, Utah, Permeable Reactive Treatment (PeRT) Wall Ground Water Investigation

Work Plan

May 2000



U.S. Department of Energy

GRAND JUNCTION OFFICE

Work Performed Under DOE Contract No. DE–AC13–96GJ87335 for the U.S. Department of Energy

U.S. Department of Energy
Grand Junction Office
2597 B¾ Road
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May 9, 2000

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Subject: Monticello, Utah, Permeable Reactive Treatment Wall Ground Water Investigation Work Plan

Enclosed are 2 copies of the *Monticello Utah Permeable Reactive Treatment (PeRT) Wall Ground Water Investigation Work Plan*. The purpose of the additional work described in the work plan is to better define the hydraulic performance of the PeRT wall. The major activities will be to measure ground water velocity and direction through the reactive gate using a colloidal borescope and a tracer study. The colloidal borescope will first be used at the end of June and the tracer study is scheduled to begin on July 10.

Please let me know if you have any issues or concerns about the proposed work outlined in this plan.

Sincerely,

Donald R. Metzler
Technical/Project Manager

Enclosure

cc w/enclosure:
J. Berwick, DOE-GJO
PTW 2.1.5 (record thru D. Dupont)
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MAC–PTW 2.1.5

Monticello, Utah Permeable Reactive Treatment (PeRT) Wall Ground Water Investigation

Work Plan

May 2000

Prepared for
U.S. Department of Energy
Albuquerque Operations Office
Grand Junction Office

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1.0 Introduction

This workplan identifies data collection activities for the Permeable Reactive Treatment (PeRT) wall at Monticello, Utah. The objective of this effort is to evaluate the hydraulic performance of the reactive barrier and to establish a baseline against which to assess performance changes over time. The activities described in this workplan will gather data for assessing transport velocities, residence times, and spatial variations in transport characteristics including the degree of vertical and lateral mixing.

1.1. Background

The Monticello Mill Tailings Site (MMTS) is a former uranium and vanadium-processing mill in the city of Monticello, Utah, that operated from the mid-1940s until 1960. The MMTS was placed on the National Priorities List (NPL) in 1989 because of potentially elevated risks associated with contaminated materials related to past milling activities. The MMTS and nearby contaminated peripheral properties have been remediated in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The U.S. Department of Energy (DOE), U.S. Environmental Protection Agency (EPA), and the State of Utah (State) have entered into a Federal Facilities Agreement (FFA) that specifies DOE as the lead agency and gives oversight authority to EPA and the State.

Operable Unit (OU) III was established to address surface water and ground water contamination from the MMTS. In 1998, a Remedial Investigation was completed for OU III, and an Interim Record of Decision was developed that included the construction of a PeRT wall downgradient of the MMTS. This PeRT wall was completed on June 30, 1999.

The PeRT wall was constructed with a permeable reactive gate and impermeable funnel walls. The permeable reactive gate was built by driving steel sheet piling down into the bedrock forming a rectangular box 103 feet long by 7.7 feet wide. The native soils inside the box were excavated and removed down to a minimum of 1 foot deep (keyed) into the bedrock aquitard. The excavated soils from inside the box were replaced with a reactive medium (–8/+20 mesh ZVI) and gravel packs upgradient and downgradient of the ZVI. The upgradient gravel pack is 1.84 feet wide composed of 13 percent –4/+20 mesh ZVI (by volume) mixed uniformly with ½-inch gravel. The middle section of the reactive gate contains 4 feet of 100 percent –8/+20 mesh ZVI. The downstream gravel pack is 1.84 feet wide composed of ½-inch gravel and includes a currently inactive air sparging system constructed of perforated polyvinyl-chloride pipe. The south impermeable wall is 240 feet in length and the north wall is 97 feet in length; the impermeable walls were installed using a slurry wall construction method. The purpose of the impermeable walls is to funnel contaminated ground water to the reactive gate for treatment.

In the summer of 1999, a monitoring network of approximately 50 wells was established centered on the reactive portion of the PeRT wall. Ground water quality samples and water level data were taken in September, October, and November 1999 and January and April 2000. Analytical data have shown a considerable reduction in contaminant concentrations as ground water moves through the PeRT wall. However, water level measurements indicate ground water is mounding behind the PeRT wall with greater than expected head drops occurring as ground water immediately enters and exits the wall. Ground water mounding behind the PeRT wall was anticipated because the slurry walls constrict the ground water flow to a smaller cross sectional area. Prior ground water modeling indicated mounding that is consistent with current levels (~3 feet); however, the greater than expected head drops that are occurring at the boundaries of the reactive gate warrant further investigation.

This workplan focuses on evaluating overall hydraulic performance, with an emphasis on further investigating the greater than expected head drops.

2.0 Work Plan Elements

Fourteen new 2-inch monitoring wells will be installed prior to initiating the activities described in this workplan. Four of these wells will be installed in the 100 percent ZVI section of the gate in May using a geoprobe; the remaining 10 wells will be installed upgradient and downgradient of the gate by a Subcontractor starting June 13, 2000. In addition, 6 core samples will be collected by the Subcontractor immediately upgradient and in contact with the reactive gate. Figure 2–1 shows the locations of the new wells and core samples.

The following tasks will be done: (1) colloidal borescope measurements, (2) a tracer study, (3) hydraulic conductivity tests on the core samples, (4) single well slug testing, and (5) a pumping test.

2.1. Task 1—Colloidal Borescope Measurements

A colloidal borescope will be used before and during the tracer study to evaluate ground water flow velocity and direction. The colloidal borescope is a downhole instrument that can be used in a 2-inch monitoring well.

2.1.1 Data Objectives

The borescope results will be used to (1) identify likely flow patterns before the start of the tracer test, (2) track/confirm ground water flow patterns during the tracer study, (3) estimate residence times in the different sections of the reactive gate, (4) help evaluate the head drops that are occurring as ground water enters and exits the reactive gate, (5) estimate transport velocities and the degree of lateral mixing and (6) evaluate the presence and influence on overall barrier performance of preferential flow zones.

2.1.2 Apparatus Description

The colloidal borescope measures the rate and direction of ground water by recording the movement of natural colloids through a wellbore. The borescope consists of a charged-couple device (CCD) camera, a flux-gate compass, an optical magnification lens, an illumination source, and stainless steel housing. The device is approximately 35 inches long and has a diameter of 1.7 inches, thus facilitating insertion into a 2-inch-diameter monitoring well. Upon insertion into a well, an electronic image magnified 140 times is transmitted to the surface, where it is viewed and analyzed.

A compass is used to align the borescope in the well, which has not been a problem with previous testing on iron barriers. The magnetic field caused by the iron is uniform such that compass readings remain accurate. There are, however, alignment rods that can be used to manually check the directional orientation from the surface. Thus, the field technician will check the compass alignment during the fieldwork as needed to ensure that flow anomalies are not the result of magnetic disturbance.

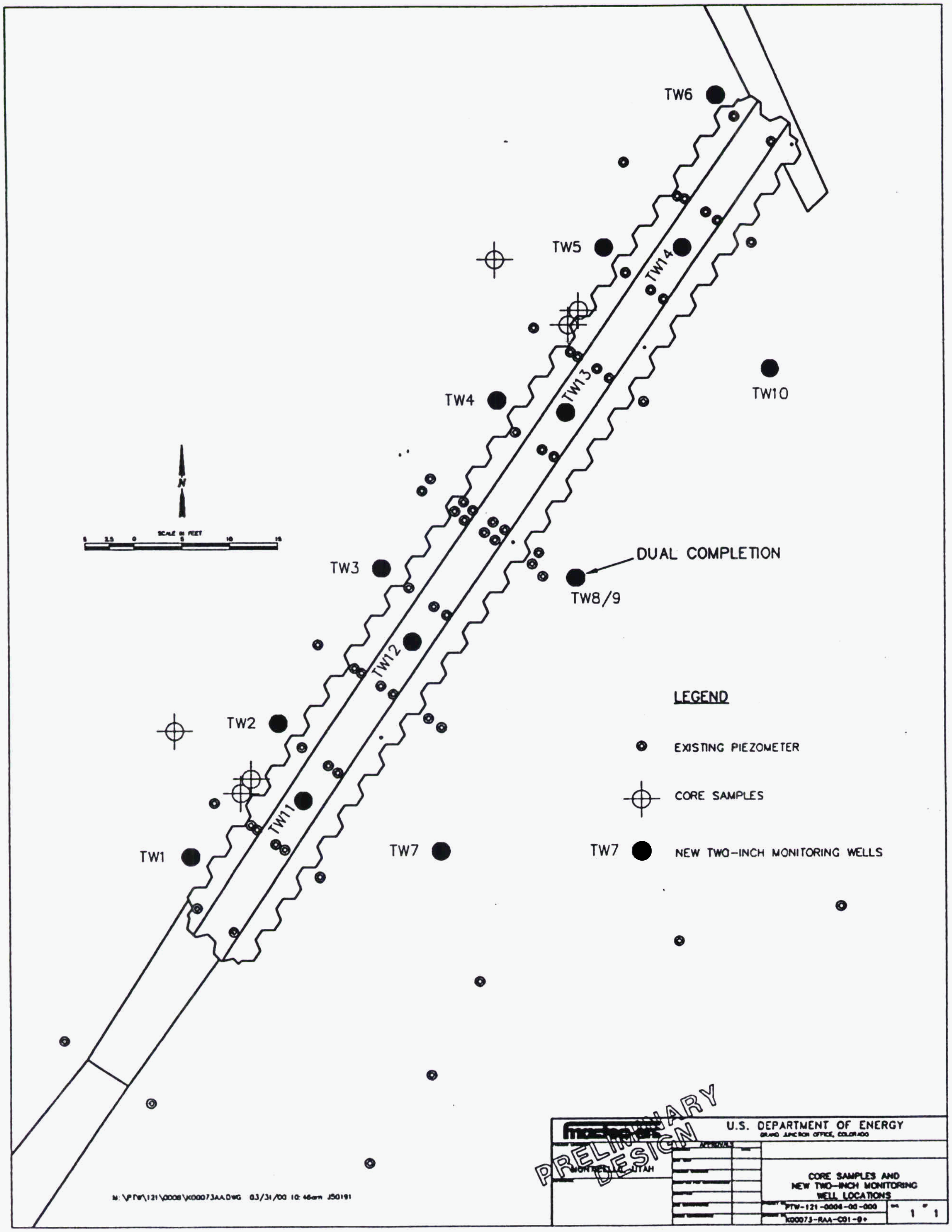


Figure 2–1. Locations of New Wells and Core Samples

As particles in the ground water pass beneath the lens, the backlighting source illuminates the particles similar to a conventional microscope with a lighted stage. A video frame-grabber digitizes individual video frames at intervals selected by the operator. A software package compares the two digitized video frames, matches particles from the two images, and assigns pixel addresses to the particles. Using this information, the software program computes and records the average particle size, number of particles, speed, and direction. In this way, a large data base is accumulated after only a few minutes of observations. Because standard VHS video uses 30 frames per second, a particle that moves 1 mm across the field of view is captured in subsequent frames 1/30 of a second apart resulting in an upper measurement velocity of approximately 3 cm/s. For low flow conditions, the delay between frames can be set for longer time periods resulting in a lower velocity range for nearly stagnant flow conditions.

Flow velocities measured by the colloidal borescope were verified using a laminar flow chamber developed at the Desert Research Institute in Boulder City, Nevada. At a flow velocity in the laminar flow chamber of 0.10 cm/s, and verified by a tracer test, the colloidal borescope measured a comparable value of 0.11 cm/s.

When evaluating data from the borescope, only those zones that display consistent horizontal laminar flow in a steady direction over a substantial time period (greater than 2 hours) are considered useful. In many wells, swirling flow zones dominate to such an extent that rate and directional data cannot be obtained. The swirling flow zones that are frequently observed may be the result of adjacent low-permeable sediments, positive skin effects, vertical flow gradients, or nearby preferential flow zones that dominate flow in the observed zone. Measurements in swirling flow zones are not suitable for velocity or directional measurements. Only when steady directional flow is observed are reliable measurements deemed possible. The identification of "steady directional flow" is performed by an experienced operator. This identification is based on the observation of an undirectional flow field for typically more than one hour. Generally, acceptable directional data show a variation of 15 to 30 degrees or less.

A significant difference between conventional hydraulic measurements and those taken with the borescope is the magnitude of ground water velocity. Borescope velocity measurements typically yield greater values than conventional methods because the instrument measures only distinct points in the wellbore, while conventional methods yield an average over a large zone. In other words, both horizontal laminar flow and swirling nondirectional flow are typically observed in wells. As noted above, in the absence of effects from underground utilities, swirling flow zones are the result of low-permeability sediments, positive skin effects, vertical flow gradients, and adjacent highly permeable zones. As an operator searches for distinct flow zones with the borescope; therefore, preferential pathways are most easily found while, in contrast, conventional testing averages both high and low flow zones.

Note that each velocity point represents the average velocity of up to 256 particles. Thus, thousands of data points are used to obtain the mean velocity that is calculated for a particular subsurface interval. Finally, it is also important to recognize that borescope velocities for preferential flow zones do not represent mean contaminant transport velocities. Mean contaminant transport will have a lower velocity because of diffusion from the preferential flow zone to the surrounding low permeability material.

2.1.3 Scope

During June and July 2000, the borescope will be used to support the multiple tracer test. Subsequently, measurements will be made to evaluate seasonal changes. To support the tracer test, each of the fourteen 2–inch wells will be tested. Additional data collection with the colloidal borescope may be done in FY 2001 and FY 2002.

Data Collection

An intensive effort will be made to obtain f low directions in each of the fourteen 2–inch wells. In general, the measurement process will be as follows:

- The borescope will be lowered until it is at the top of but fully within the well screen. The flow zone at this location will be evaluated for approximately one hour. At the end of this time period, the operator will review the colloid flow field on the video screen. If the flow field is either stable or shows signs of stability, then the measurement process will continue until a minimum two-hour flow file is obtained. When convenient with respect to site access, power, and security, the instrument will be left in the well to record data overnight.

- If the operator deems that a stable flow field is unlikely, the borescope will be lowered six inches and the measurement process repeated. The borescope will be lowered in this manner until a stable flow zone is encountered or the bottom of the well-screen is reached.

- Once a stable flow field is found, the borescope will be moved to the next well. More than one flow field will typically not be determined during the initial measurements in a well. The reason for moving to the other wells is because of the long measurement time involved. The approach, therefore, is to obtain data from as many wells as possible, and to focus on anomalous wells once the initial data are reviewed.

While in the field, the operator will review the data for each set of wells: wells-within-the-barrier, wells-upgradient of the barrier, and wells-downgradient of the barrier. The purpose of this review is to consider whether the data are internally consistent. For example, if all four wells within the barrier show flow in the same direction, then there is probably no need to search for additional flow zones in these wells. There are, however, several instances in which additional data collection will be performed. These are:

- Flow directions from a particular group of wells are inconsistent. Examples include finding flow zones within the barrier differing by 180° or finding excellent flow zones in some wells within a group and not others. At the judgment of the operator, previously-measured flow zones will be checked and/or smaller increments will be evaluated in order to find flow zones in all of the wells.

- Flow velocities are significantly different within a particular group of wells. Once again, previously-measured flow zones will be checked and/or smaller increments or different locations will be evaluated in order to find other flow zones.

Data Presentation

The software with the borescope provides the data in two formats as shown in the attached figures. Figure 2–2 shows directional and velocity data versus time. These data show a stable, easy-to-interpret flow zone. The directional data are also provided in a rose diagram (Figure 2–3). At the bottom of Figure 2–3, the velocity statistics are presented. The corrected values are based on laboratory experiments (Kearl 1997) that demonstrated that dividing the mean velocity by four provided the best estimate of actual average flow velocity.

Figures 2–4 and 2–5 show data that are more difficult to interpret. Figure 2–4 shows an unstable velocity and direction. The rose diagram may provide some information regarding direction, but such data may be unreliable and must be considered within the context of the other data obtained on site.

Repetitive Measurements

Few data exist regarding seasonal changes as measured with a downhole flow meter such as the borescope. Thus, the borescope will be used to check prominent flow zones at least on a bi-annual basis.

A complete data set will be obtained during the summer of 2000. Several of the prominent flow zones will be selected for repeat measurements which will be made in October or November of 2000. Similarly, these same zones will be checked once again during the spring or summer of 2001. The extent of the fiscal-2001 monitoring program will be determined based on how well the data compare from one measurement period to the next. The number of measurements cannot be specified in advance until it is known how much time is required to obtain a useful data set.

Use of the Measurements

The immediate use of the measurements will be to evaluate anomalies in the flow field. For example, the barrier is designed for flow to pass through it in a perpendicular fashion. Deviations from the perpendicular suggest variations in the design or its implementation may have occurred.

In general, the borescope should provide a broad view of the flow field that will be refined by the tracer test. In a previous study (Korte et al. 2000), the borescope was used to identify the fastest flow zones in preparation for a tracer test. Once the tracer was injected, sampling focused initially on those wells identified as being within a preferential pathway. Tracer appearance correlated very well with the borescope data in that preferential pathways showed the tracer very quickly. On the other hand, wells in which the borescope found no flow zones eventually did show the tracer.

Data Interpretation

Because of heterogeneity and limited access to the subsurface, no single method will provide a detailed description of the flow field. Hence, data from the borescope will be interpreted in conjunction with the data from the other hydraulic measurements: single-well slug tests (see Section 2.4), water level elevations, and multiple tracer test to allow the investigators to select the optimum measurement approach to evaluate the long-term hydraulic performance of the

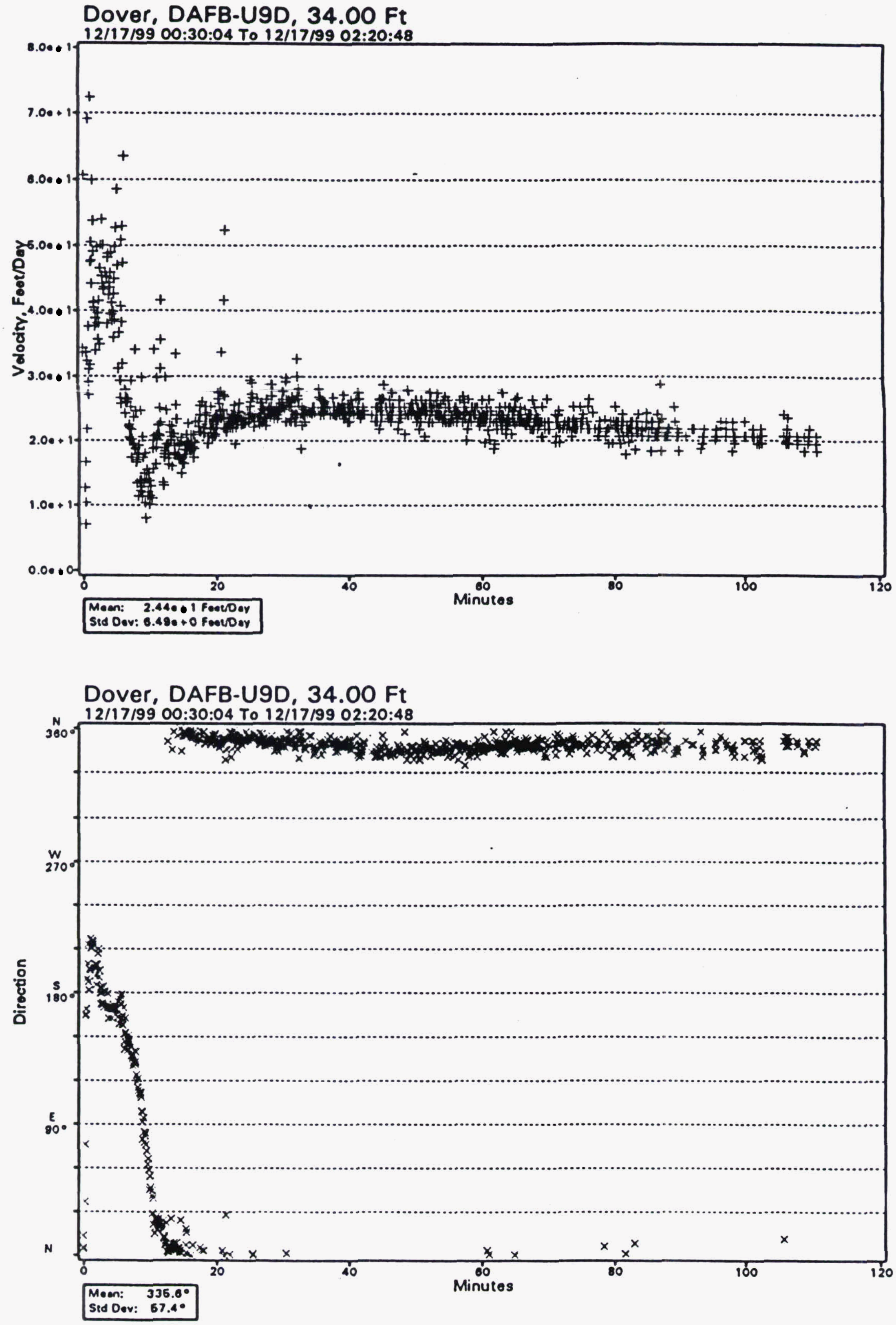
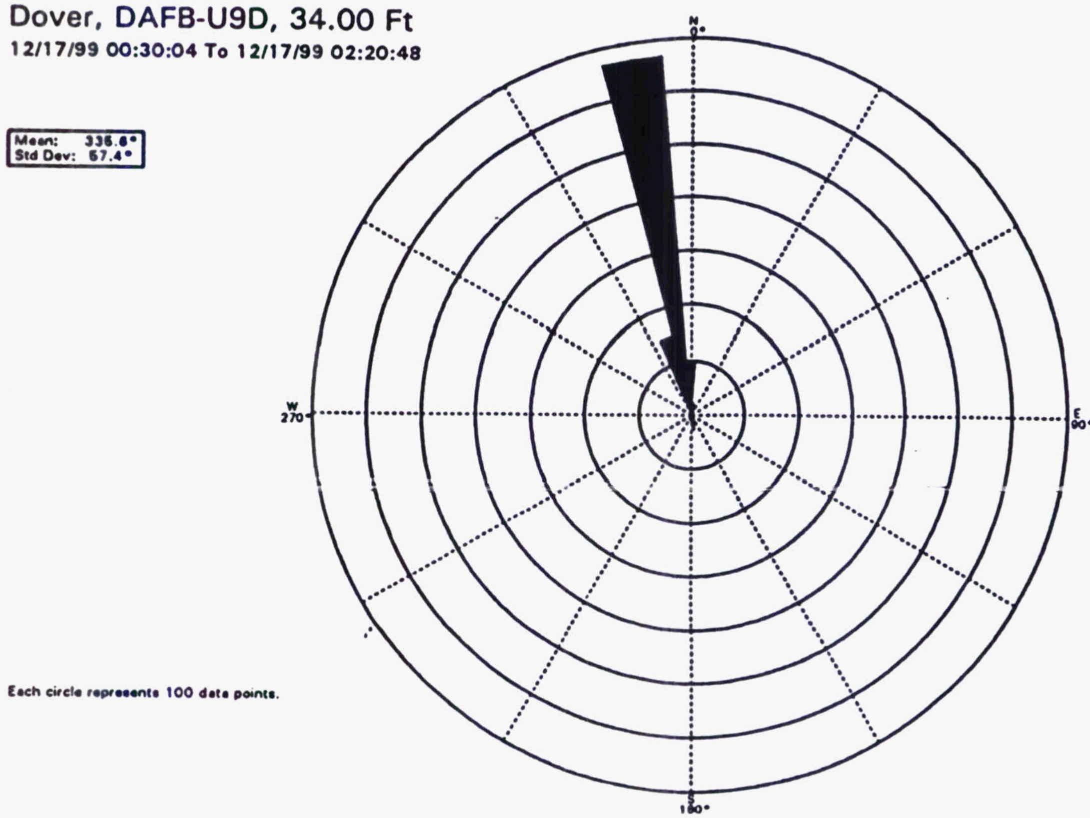


Figure 2–2. Directional and Velocity Data versus Time



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12/17/99 00:30:04 To 12/17/99 02:20:48

Direction Statistics

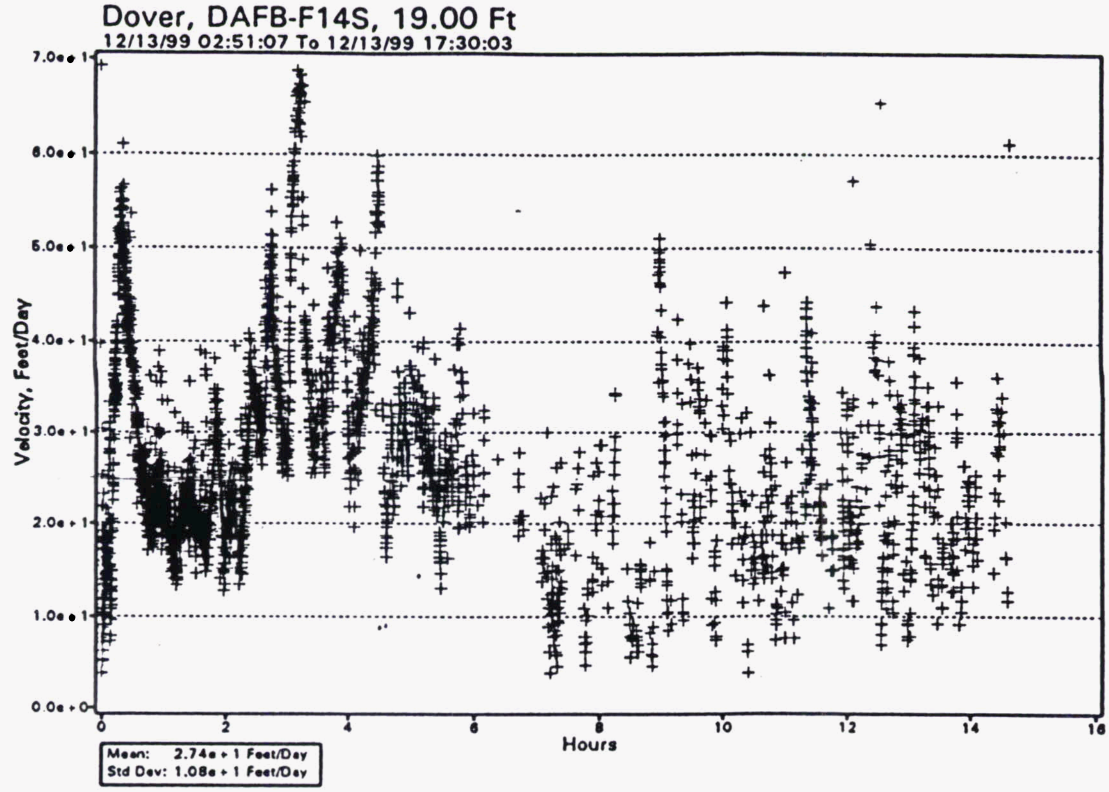
Mean: 335.6°
Std Dev: 57.4°

Velocity Statistics

Measured	Units	Mean	Std Dev
	Feet/Day	2.437e+1	6.490e+0
	Microns/Sec	8.596e+1	2.290e+1
	Feet/Year	8.894e+3	2.369e+3
	Cm/Sec	8.596e-3	2.290e-3
	Meters/Day	7.427e+0	1.978e+0
	Meters/Year	2.711e+3	7.221e+2

Corrected	Units	Mean/4	Mean/3	Mean/2
	Feet/Day	6.092e+0	8.122e+0	1.218e+1
	Microns/Sec	2.149e+1	2.865e+1	4.298e+1
	Feet/Year	2.223e+3	2.965e+3	4.447e+3
	Cm/Sec	2.149e-3	2.865e-3	4.298e-3
	Meters/Day	1.857e+0	2.476e+0	3.713e+0
	Meters/Year	6.777e+2	9.036e+2	1.355e+3

Figure 2–3. Rose Diagram—Directional Data



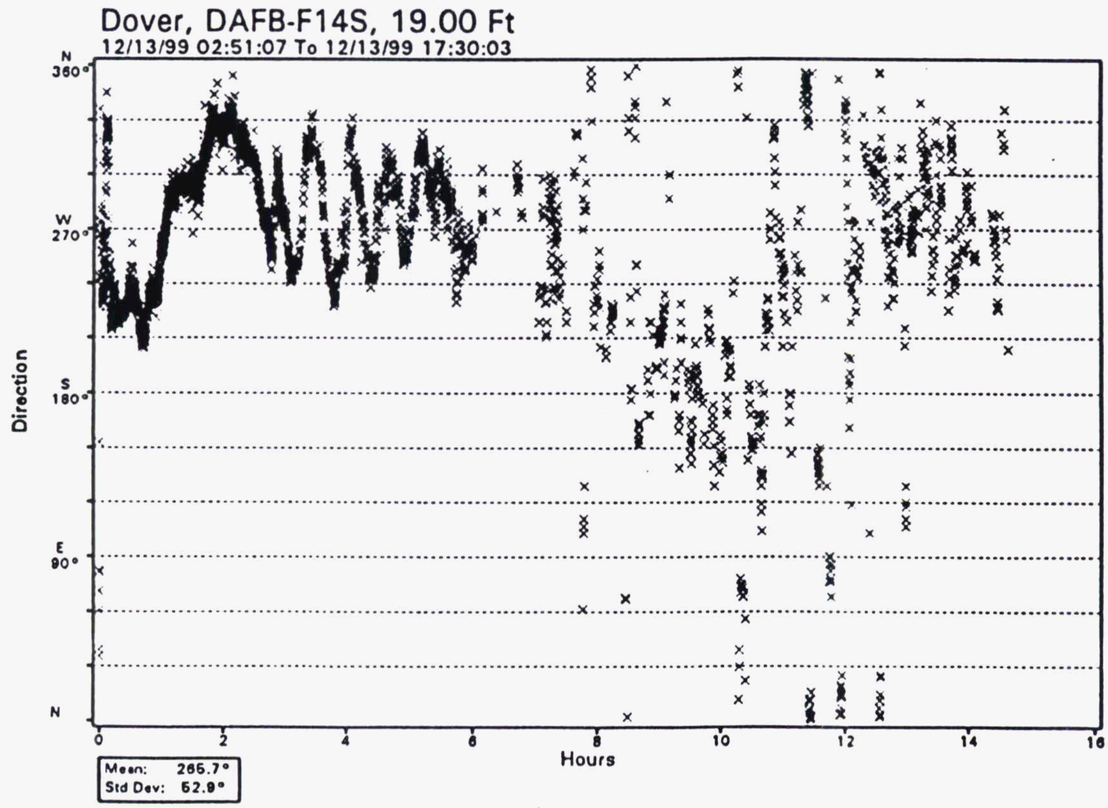
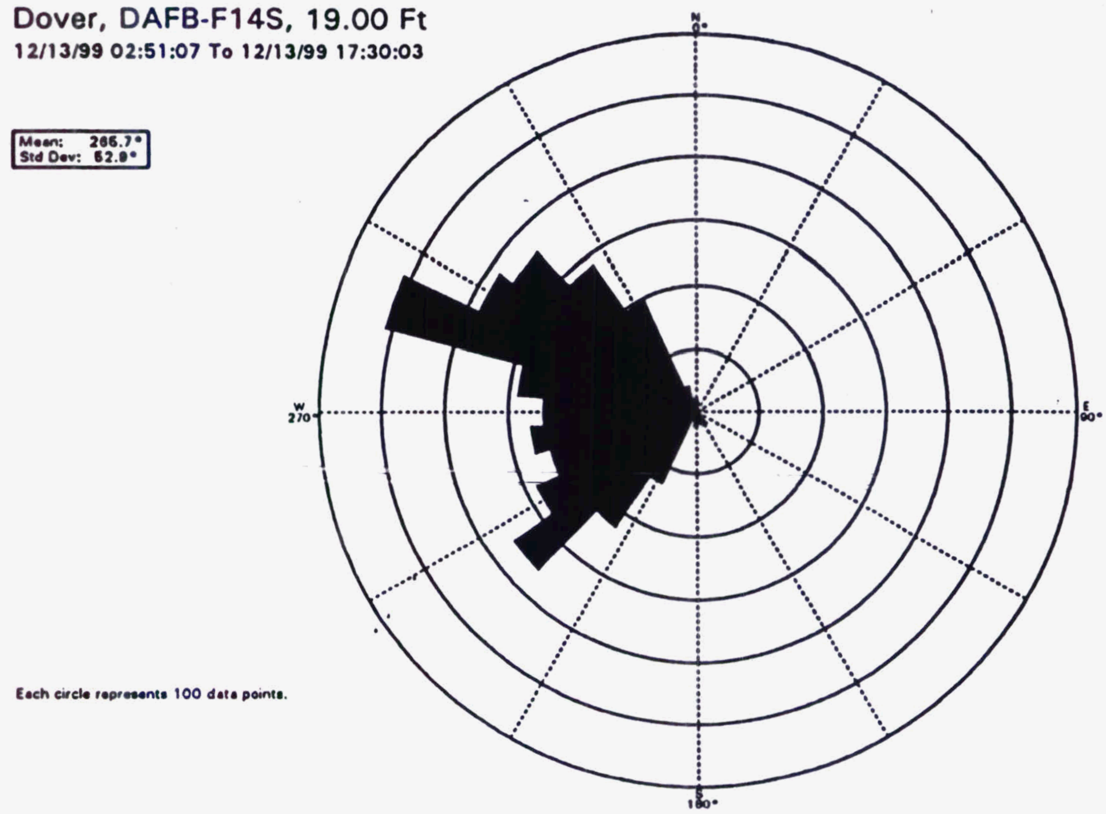


Figure 2–4. Unstable Velocity and Direction Data



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12/13/99 02:51:07 To 12/13/99 17:30:03

Direction Statistics

Mean: 265.7°
Std Dev: 52.9°

Velocity Statistics

Measured	Units	Mean	Std Dev
	Feet/Day	2.741e+1	1.084e+1
	Microns/Sec	9.668e+1	3.823e+1
	Feet/Year	1.000e+4	3.955e+3
	Cm/Sec	9.668e-3	3.823e-3
	Meters/Day	8.353e+0	3.303e+0
	Meters/Year	3.049e+3	1.206e+3

Corrected	Units	Mean/4	Mean/3	Mean/2
	Feet/Day	6.852e+0	9.135e+0	1.370e+1
	Microns/Sec	2.417e+1	3.223e+1	4.834e+1
	Feet/Year	2.501e+3	3.334e+3	5.002e+3
	Cm/Sec	2.417e-3	3.223e-3	4.834e-3
	Meters/Day	2.088e+0	2.784e+0	4.177e+0
	Meters/Year	7.622e+2	1.016e+3	1.524e+3

Figure 2–5. Rose Diagram—Unstable Directional Data

barrier. In that context, data interpretation from the borescope is expected to be straightforward and will answer questions such as:

- Whether the entire barrier is treating contaminated water,
- Whether the design residence time is being achieved, and
- Whether there are significant preferential flow zones upgradient, within or downgradient of the barrier.

For long-term monitoring, the borescope will assist in determining:

- Whether there are significant seasonal variations
- The scope of hydraulic measurements needed for long-term performance monitoring.

Specifically, one scenario may be that the same flow zones are prominent no matter what the season. In such cases, then water level elevations on a quarterly-to-annual basis may be selected as the most expedient means of evaluating hydraulic changes. On the other hand, large variations in location and magnitude of flow zones would suggest that both continuous water level measurements and frequent borescope measurements are necessary.

Summary

The colloidal borescope will support the hydraulic evaluation at the Monticello barrier by providing information on the location and magnitude of preferential flow zones. The data to be obtained is constrained by the time required per measurement and the lack of knowledge regarding the nature and magnitude of the flow zones. The borescope is expected to be an important long-term tool for evaluating changes in the barrier's hydraulic performance. A less useful circumstance would be that such long measurement periods are needed, that sufficient data cannot be obtained in the time available. In the latter case, the data will be used to describe the flow field, but the long-term value of repetitive borescope measurements will be limited.

2.2. Task 2—Tracer Study

A multiple point, continuous injection tracer study will be conducted on the reactive gate portion of the PeRT wall.

2.2.1 Data Objectives

The overall objectives are to evaluate the hydraulic performance and to provide a baseline against which to assess changes in barrier performance over time. The tracer test will help assess transport velocities through the reactive gate and residence times within each section of the gate. The use of tracers in multiple locations will also provide insight on the transport characteristics and the degree of vertical and lateral mixing of ground waters moving through the barrier. Finally, the results will be used to identify preferential flow zones through the reactive gate.

It should be noted that tracer tests at other reactive barriers have failed when the tracer was not detected. It is difficult to assess the previous tests without evaluating the specific information with regard to how those tests were structured. It may be that not enough mass was put into the system to allow detection once dispersion, dilution, and any reactive losses were accounted for. It may be that the sampling design allowed the breakthrough of a pulse injection to be missed, either due to timing or due to insufficient sampling points to compensate for heterogeneity and preferential flow paths. It is also possible that the tracer behaved differently in the reactive materials than anticipated and, thus, the losses during transport were underestimated. Because of these considerations, however, the PeRT test has the following components: continuous injection to ensure sufficient total mass; high frequency sampling over a significant period of time; high density of sampling points including the inclusion of additional sampling locations to monitor lateral transport resulting from mounding; and laboratory evaluations of the tracers with respect to environmental conditions and potential interferences. These activities are believed to be sufficient to ensure that the test will successfully measure transport behavior, even in the presence of significant heterogeneity.

2.2.2 Tracer Selection

The ideal tracer has the following characteristics:

- Easily introduced into the subsurface
- Nonhazardous
- Inexpensive
- Low reactivity
- No detrimental impact on the barrier
- Detected and differentiated in a single analysis (for multiple tracers)
- Straight forward sampling and analytical methods
- Detected above background
- Easily flushed allowing the possibility of retesting

A wide variety of ground water tracers are available to choose from that have many of the characteristics listed above and have been field tested. The tracers generally fall into three categories: anionic tracers (iodide, bromide), fluorescent dyes (eosine, fluorescien), and noble gases (helium, neon, argon). Unfortunately, recent tests with dye tracers have shown that these react in the presence of zero valent iron. Therefore, dye tracers will not be used in this tracer study.

The use of anion tracers such as Br, I, and Cl was also evaluated because they are easily measured with ion selective electrodes. However, further investigation indicates that a Cl:Br ratio of 180 to 1 will cause severe interference. Thus, the relatively high chloride present at the site limits the sensitivity of bromide. Similarly, small amounts of iodide cause such a significant interference with bromide that the two cannot be used simultaneously if ion selective electrodes are used for quantification.

The benefits of using noble gases are that they are nonreactive in all environments, they can be analyzed using simple gas chromatography (GC) methods, multiple gases can be analyzed from a single sample, and there is no volume displacement during injection or sampling because the gas is introduced by passive diffusion into the ground water in the injection well and sampled by passive diffusion through permeable membrane samplers. The disadvantages are that loss of the gas can occur at a number of points during the sampling and analysis process, resulting in reduced concentrations or false non-detects, and additional time is required to bring injection concentrations to equilibrium. A further disadvantage is potential loss of dissolved gas into the vadose zone in shallow systems, resulting in reduced concentrations and lower apparent transport rates. However, these disadvantages can be accounted for during the study design and interpretation of the results. For example, concerns with tracer loss will be addressed by using continuous injection as previously described, and by using an anionic tracer (bromide) that will permit calculation of gas losses to the vadose zone. In this way, sufficient tracer will be added to assure detection downgradient from the source, and the inert gas data can be validated by comparison to the results with the anion tracer. Note that the bromide will not have to be measured in the field, although equipment will be present should there be time available to complete the analyses.

Based on a thorough review of the tracer options, a combination of gas and anion tracers will be used. Specifically, helium, argon, and neon gas tracers and a bromide anion tracer will be used.

2.2.3 Scope

Tracers will be injected into the following four locations immediately upgradient of the reactive gate: wells R1–M2, T1–S, T1–D, and R1–M5 (see Figure 2–6). Helium will be used at the barrier end locations (R1–M2 and R1–M5) and argon and neon tracers in the central well pair (T1–S, D). To better track vertical flow patterns, neon will be used in one well of the well pair and argon will be used in the other. In addition, the anion tracer (sodium bromide) will be used along with the gas tracer in the shallow central well (T1–S). Co-injection of bromide and gas tracers has been successfully performed in previous tracer studies conducted at Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee. Because of the 80–ft separation of the two distal injection wells and the unlikelihood that the tracers will transport that distance laterally, the same gas tracer will be used at the distal locations to reduce the analytical complexity.

The method of injection for the bromide tracer will be continuous flux-controlled injection using peristaltic pumps controlled by a Campbell data logger. A concentrated tracer solution will be pumped into the injection well and circulated within the well casing to achieve a bromide concentration of 1,000 mg/L in the well. This concentration was estimated based on average ground water velocity and the cross sectional area of the screened interval. Specific conductance of the water in the wellbore will be monitored using a flow-through device. The conductivity will be calibrated to tracer concentration by analyzing samples taken from the injection well during injection. Constant concentration in the injection well is maintained by setting a target conductivity and a tolerance. When the bromide concentration in the well drops below 1,000 mg/L, the pump is triggered to drip in tracer solution until the concentration once again rises above this concentration. The datalogger controls the input of tracer solution and records the rate and time of pumping. Thus, a total injection mass can be accurately determined, and ground water flux through the injection well can be estimated. The entire injection system including data logger and peristaltic pumps will be powered using a bank of solar panels and all four injection wells, including conductivity/temperature probes, will be run from a single Campbell CR10 datalogger equipped with a multiplexer and data storage module.

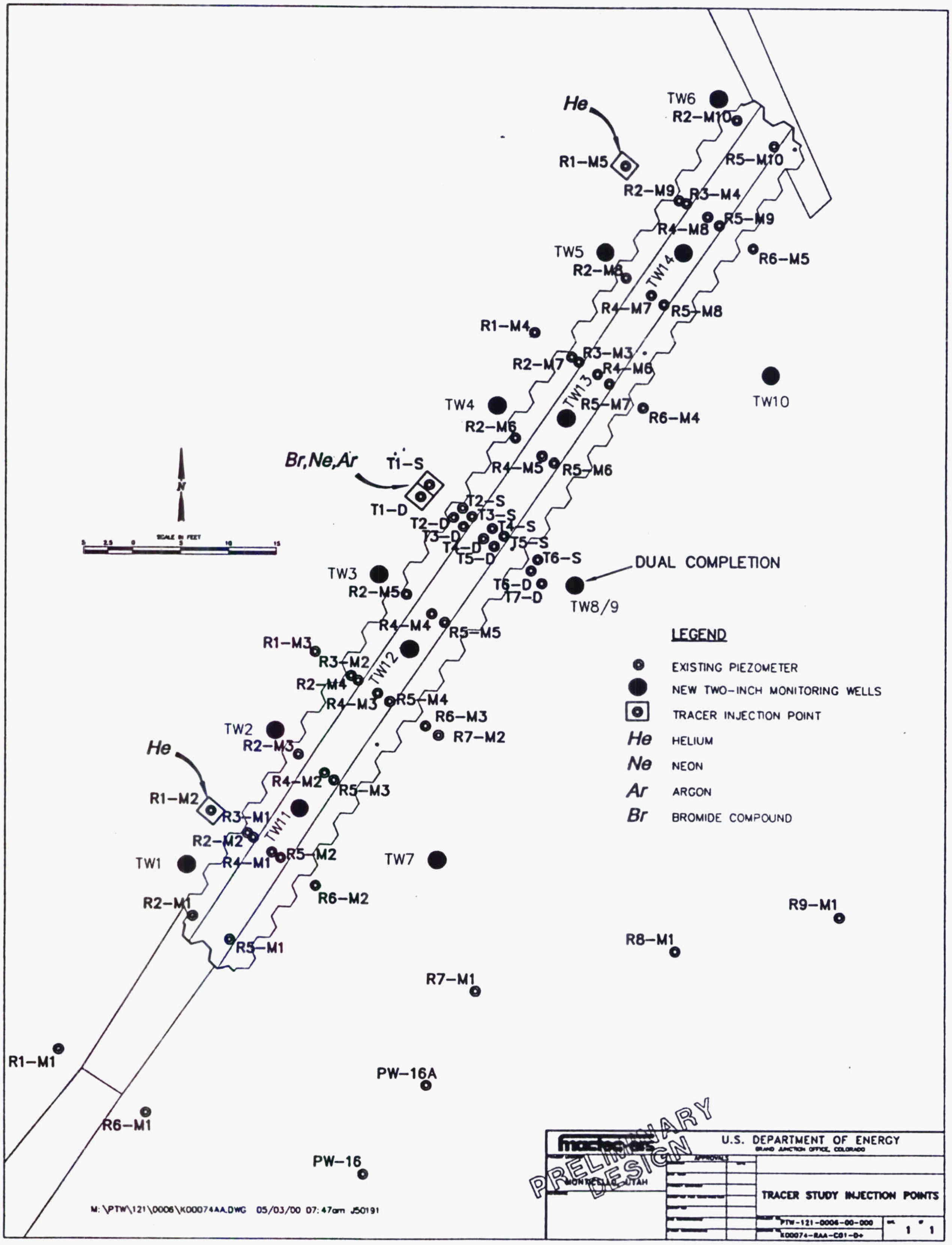


Figure 2–6. Locations for the Tracer Study

The gas tracers will be introduced by continuous injection using a diffusion method. A coil of 1/8-inch Teflon tubing will be inserted into the screened portion of the injection well. The gas tracer will be continuously pumped through the injection tubing. The gas will diffuse directly into the ground water surrounding the injection tubing, coming to an equilibrium concentration that will be relatively steady-state, with the exception of minor temperature fluctuations. The mass of tracer injected will be dependent on the ground water flux through the well and the ground water temperature. Thus, the concentration is not known a priori but is determined through sampling during the course of the test. The equilibration time for these wells should be rapid, due to the small wellbore volumes and relatively low flux through the well screens based on hydraulic gradient. Expected concentrations near the source should be several orders of magnitude greater than the detection limit. Indeed, the contrast between the source concentration and that, which can be detected downgradient, is probably greatest with the gas tracers. Hence, the gas tracers should provide the most detailed view of the flow patterns associated with the PeRT wall.

Tracer injection will occur over a period of 5 days, followed by a recovery period of approximately 7 days. The injection and recovery periods may be adjusted based on the transport behavior as the tracer test is in progress. Total time of the field test, including setup and baseline sampling is projected to be two weeks.

Sampling and Analysis

Monitoring will occur in multiple locations within and downgradient of the reactive gate to determine transport rates and directions. Sampling will be done using dedicated tubing and peristaltic pumps and low-purge methods in order to minimize disturbance to the flow-field. Should a preferential flow path be identified with the colloidal borescope, the inlet for the dedicated sample tubing will be placed at that depth. If there are not preferential paths identified in a particular well, the sample tubing will be placed in the middle of the screen. Sampling will occur in 30 wells along 5 transects across the barrier, plus all of the new 2-inch well locations upgradient, within, and below the barrier (Figure 2–6).

Existing wells: Transect 1—R2–M2, R3–M1, R4–M1, R5–M2, and R6–M2.
Transect 2—R2–M4, R3–M2, R4–M3, R5–M4, and R6–M3.
Transect 3—T2–S,D, T3–S,D, T4–S,D, T5–S,D, and T6–S,D.
Transect 4—R2–M7, R3–M3, R4–M6, R5–M7, and R6–M4.
Transect 5—R2–M9, R3–M4, R4–M8, R5–M9, and R6–M5.

New two-inch wells: 6 upgradient wells (TW1–6)
4 wells within barrier (TW11–14)
4 wells downgradient (TW7–10)

All wells will be sampled prior to injection to ensure that there are no significant background concentrations of the tracers or any other analytes that may interfere with the tracer analyses. The sampling schedule for the tracers will be adjusted according to the breakthrough pattern of the tracers. Initially, samples will be obtained at a minimum of every two hours to capture early breakthrough behavior when concentrations are changing rapidly. The sampling frequency can then be decreased as the tracer concentrations approach steady state. Thus, while the sampling frequency will again be higher during the initial recovery when concentrations are decreasing rapidly, the number of locations will be fewer.

The quarterly sampling event scheduled for July will obtain a complete set of geochemical and contaminant parameters shortly after the tracer study is complete. As with the data collection prior to the tracer test, these data are needed for assurance that geochemical conditions did not change during the tracer test. Typically, the two sets of geochemical data will not be used in the test interpretation. However, significant changes in the distribution of contaminants or naturally-occurring constituents would indicate the presence of some outside perturbation to the system that requires consideration in the data interpretation.

Samples for the bromide tracer will be collected in 30-ml Nalgene sample containers, labeled as to location and time, and stored immediately in an ice chest while in the field. Analyses will either be done on location or shipped back to ORNL for laboratory analysis. Selected samples will be analyzed at ORNL to confirm the accuracy of field-determined concentrations and to test samples where concentrations are below the detection limit for field methods.

For the gas tracers, samples will be obtained using a closed system to prevent gas leakage, and headspace samples will be obtained and analyzed using gas chromatography with a thermal conductivity detector. Relatively small sample volumes (40 mL) for analysis are needed, thus reducing the volumes removed from the wells (minimal perturbation). Blanks and replicates of selected samples will also be analyzed to ensure data quality. An advantage of gas tracers is that all three gases are measured with a single injection. Hence, as one tracer shows up in a transect different from the one in which it was injected, it will be detected immediately.

Samples will be collected in order from those closest to the injection wells to those furthest away. It is also anticipated that data from the colloidal borescope will guide the selection of the initial sample locations and frequency. Subsequent sampling and analysis along any given transect through the barrier will depend on the pattern of detection. Samples furthest away from the injection point will not be analyzed until detection occurs in the upgradient barrier wells. Once detection has occurred, that monitoring point will be analyzed for the duration of the test. All wells will be sampled, however, and samples will be retained until data analysis is complete. In this way, time is saved by avoiding unnecessary analysis in the field, while retaining the capability of doing more frequent analysis, if necessary.

Water Level Monitoring

To establish ground water flow patterns, water levels in and around the barrier will be measured daily throughout the course of the field tracer test. Water levels will be obtained manually using a water level meter. Water levels in the four injection wells will be continuously recorded along with the conductivity.

Data Interpretation

The performance of the reactive barrier needs to be assessed with respect to both the hydraulic performance (ability to effectively capture contaminated ground water) and the geochemical performance (ability to effectively sequester the contaminants of concern). The hydraulic characteristics determine the amount and distribution of ground water flux through the barrier and the residence times within portions of the barrier. These parameters, in turn, have a large impact on geochemical reactions involving both contaminants and other solutes. For example, pH and redox are both impacted by ground water dynamics which, in turn, control the rate of mineral precipitation. Mineral precipitation will impact permeability, reducing ground water flow to the affected area, increasing residence time, and redistributing flow. The tracer study will be an important tool for evaluating these issues.

The tracer study will identify the current performance of the barrier and provide a comprehensive baseline for evaluating changes in performance over time. Analysis of the tracer test and hydraulic head data will provide a measure of:

- estimated flux through the barrier;
- transport patterns and heterogeneity; and
- ground-water velocities and residence times through various portions of the barrier.

These evaluations will be based on mapping of the data and on analytical calculations.

Although not part of this workplan, data interpretation will continue after this fiscal year. For example, the mass balance calculations needed to provide a more complete measure of flux through the barrier require the use of flow and transport models. Modeling will permit refinement of the aquifer parameters used in previous models developed to determine barrier design criteria, and to evaluate the heterogeneous nature of flow and transport through the barrier. Modeling will also provide a means for evaluating any changes observed during the ongoing monitoring effort.

2.3. Task 3—Laboratory Hydraulic Conductivity Testing

This task will examine the core samples taken as part of the drilling subcontract. The laboratory evaluations described in this task will only be done if high quality core samples are obtained.

2.3.1 Data Objectives

Six core samples will be taken upgradient of the PeRT wall. Four will be in contact with the upgradient ZVI/gravel section and two will be in undisturbed native aquifer material approximately 6 feet upgradient of the wall. The core samples in contact with the PeRT wall will be examined for influences/changes that may have occurred from the vibratory emplacement and removal of the sheet piling. In particular, they will be examined for a smear or compaction zone that could be impacting hydraulic conductivity. The purpose of this task is to compare the hydraulic conductivity of this potential smear zone to the "background" hydraulic conductivity of the native aquifer.

2.3.2 Scope

A subcontract will be arranged with a qualified lab to perform hydraulic conductivity tests on the six core samples that will be collected as part of the drilling subcontract. The likely testing method will be a falling head and constant tailwater procedure (Method B) under ASTM 5856–95, "Standard Test Measurement of Hydraulic Conductivity of Porous Material Using a

Rigid Wall, Compaction Mold Permeameter." This is generally done as a vertical column test; however, this will need to be modified to pass water through the core samples in the same direction that occurs in the field. In addition to hydraulic conductivity, bulk density would also be measured as a method to compare the core samples for potential compaction from the sheet piling. The core samples will be visually examined and geologically logged. If they are of sufficient quality, they will be sent to a laboratory for evaluation. The laboratory will be required to produce a letter report that describes the testing procedure and results. Individual results will be developed for each of the six core samples.

2.4. Single Well Slug Testing

2.4.1 Objectives

Single well slug tests will be performed on all of the 2-inch wells, including those wells within the barrier. Testing of the upgradient and within barrier wells will be completed prior to initiation of the tracer test. The downgradient wells will also be measured, but testing may not occur until during or after the tracer test.

2.4.2 Scope of Work

Conventional slug testing cannot be used for the wells within the barrier because of the iron's high permeability. Thus, the test method will employ a pressure-tight cap on the wellhead and nitrogen to depress the water within the well. When the pressure is released, the resulting recovery rate can be used to calculate the hydraulic conductivity. The data acquisition equipment and software can record data at a rate of approximately 18 points per second. Once the data are obtained, conventional data reduction methods can be used. This approach has been used successively at other iron barriers where hydraulic conductivities of approximately 300 ft/day were measured.

2.5. Pumping Test

2.5.1 Objectives

A pumping test will be conducted to estimate the volumetric rate at which ground water is entering the reactive gate. Pumping test drawdown data will also be analyzed for vertical boundary effects.

2.5.2 Scope of Work

Ground water will be pumped from the air sparging system that is in the downgradient gravel pack of the reactive gate. The system consists of a horizontal, perforated 2-inch PVC pipe that runs nearly the length of the gate, about 3-inches from the bottom. A non-perforated vertical riser (2-inch PVC) connects the screen to the surface at the north end of the gate.

The test will proceed as a step-test to determine the maximum sustainable yield from the horizontal well. Pumping will be by suction lift. Water will be withdrawn through 1- to 1.5-inch diameter PVC placed inside and to the bottom of the vertical riser. It is anticipated that the maximum pumping rate under these conditions will be about 50 gpm. Water levels in the pumping well will be monitored using a pressure transducer, placed slightly above the top of the horizontal screen, and data logger. Water levels in other wells within and outside of the gate (e.g. in the T1 to T6 transect) will also be monitored during the test using transducers and data logger. Ground water levels in all PeRT monitoring wells will be measured prior to the pumping test.

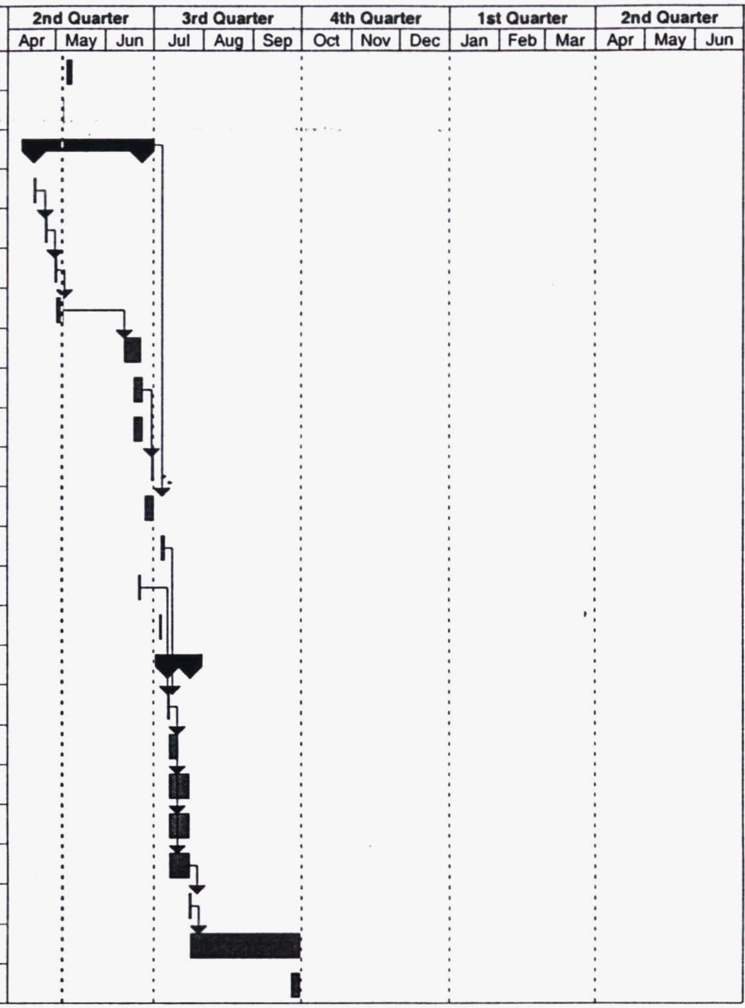
The initial pumping rate will be about 10 gpm and will be steady until a static water level is attained in the pumping well. This process will then be repeated at increased rates until a static level in the pumping well is attained at, or close to, the maximum available drawdown. When that occurs, the rate of water entering the gate is equal to the rate of withdrawl. Flow will be gauged using an in-line flow meter. Water will be discharged to Montezuma Creek. About 1 pore volume (approximately 20,000 gallons) from the reactive gate will be withdrawn during the test.

3.0 Schedule

Figure 3–1 presents the schedule for the activities included in this workplan.

PeRT Wall Characterization Activities

ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	Place 4 2-inch Wells in the ZVI	3d	5/8/00	5/10/00		GJO
2	Complete Work plan	1d	5/5/00	5/5/00		GJO
3	**Drill Remaining 2-inch Wells**	**51d**	**4/18/00**	**6/23/00**		
4	Release RfP	1d	4/18/00	4/18/00		GJO
5	Site Tour	1d	4/25/00	4/25/00	4	GJO
6	Responses to RfP Due	1d	5/1/00	5/1/00	5	GJO
7	Select Subcontractor	4d	5/2/00	5/5/00	6	GJO
8	Drill Wells	10d	6/13/00	6/22/00	7	GJO
9	Evaluate/Log Core Samples	5d	6/19/00	6/23/00		GJO
10	Develop Wells	5d	6/19/00	6/23/00		GJO
11	Ship Cores to Hydaulic Conductivity Lab	1d	6/30/00	6/30/00	9	GJO
12	Initial Borescope Measurements	5d	6/26/00	6/30/00	3	
13	Slug tests	2d	7/6/00	7/7/00		ORNL
14	Initial Tracer Study Readiness Review	1d	6/22/00	6/22/00		GJO/ORNL
15	Final Tracer Study Readiness Review	1d	7/5/00	7/5/00		GJO/ORNL
16	**Tracer Study Field Activities**	**14d**	**7/10/00**	**7/23/00**		
17	Site Mobilization	1d	7/10/00	7/10/00	13,14	GJO/ORNL
18	Tracer Injections	5d	7/11/00	7/15/00	17	ORNL
19	Water Level Measurements	12d	7/11/00	7/22/00	17	GJO
20	Tracer Monitoring	12d	7/11/00	7/22/00	17	ORNL/GJO
21	Colloidal Borescope Use	12d	7/11/00	7/22/00	17	ORNL
22	Site Demobilization	1d	7/23/00	7/23/00	21	GJO/ORNL
23	Tracer Study Writeup	50d	7/24/00	9/29/00	22	ORNL/GJO
24	Pumping Test	5d	9/25/00	9/29/00		GJO



Project: PeRT Wall Charac
Date: 5/5/00

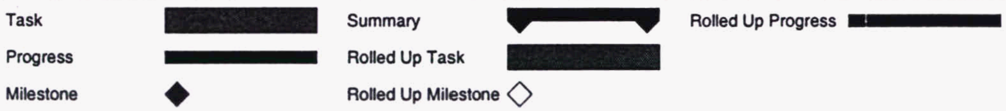


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Figure 3–1. Workplan Activities Schedule

4.0 References

Kearl, P. 1997. "Observations of particle movement in a monitoring well using the colloidal borescope," *Journal of Hydrology*, 200:323-344.

Korte, N., P.M. Kearl, R.L. Siegrist, M.T. Muck, and R.M. Schlosser, 2000. "An evaluation of horizontal recirculation using single-well tests, pumping tests, tracer tests, and the colloidal borescope," *Ground Water Monitoring and Remediation*, Winter: 78-85.

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Attachment 1

Equipment/Supplies	Quantity	Source
Tracers		
Helium compressed gas cylinder	1	ORNL
Neon compressed gas cylinder	1	ORNL
Argon compressed gas cylinder	1	ORNL
Sodium Bromide	1 Kg	ORNL
Injection Tubing		
Copper and Teflon (gases)	[a]	ORNL
Nylon/poly for bromide	[a]	ORNL
Peristaltic pumps	6	ORNL–GJO
Teflon sample tubing	[a]	ORNL–GJO
40 ml VOA vials (gas samples)	[a]	ORNL
Campbell datalogger and solar panel system	1	ORNL
30 ml Nalgene sample bottles	[a]	GJO
Large Nalgene carboys for tracer solutions	4	ORNL
Specification probe (bromide)	1	ORNL–GJO
Ice chest	1	ORNL–GJO
Water level measurement equipment	NA	ORNL–GJO
DI water supply	[a]	GJO
Gloves/wipes	[a]	GJO
Conductivity/temperature probes	4	ORNL
Mobile Laboratory	1	GJO

[a]Bulk supplies will be transported to the site

Key: ORNL = Oak Ridge National Laboratory
ORNL–GJO = Oak Ridge National Laboratory in Grand Junction, Colorado
GJO = DOE/MACTEC–ERS
NA = not applicable

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